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SURVEY OF NEMATODES IN EASTERN OREGON AND WASHINGTON FIELD CROPS

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Introduction

Nematodes are roundworms that occur worldwide in all environments. Most nematodes are beneficial to agriculture because they contribute to degradation of crop residue and are important members in the food chain. However, about 15 percent of the species are parasitic to plants and cause crop losses valued at \$8 billion annually in the United States and \$78 billion worldwide (Barker et al., 1998). Most of the plant parasites are tiny (less than one millimeter long; 0.04 in) and live in soil (Barker et al., 1998; Evans et al., 1993; Jenkins and Taylor, 1967). Symptoms of nematode damage are easily confused with symptoms of nutrient deficiency, drought, or root disease. Moreover, damage by nematodes can lead to more intense infection of roots by fungal pathogens. The combined effect of fungal and nematode damage is often more pronounced than caused by either of the disease agents acting alone.

Plant parasitic nematodes are well known for damaging irrigated crops in the Pacific Northwest (Jensen, 1961). Most emphasis has been on higher value crops such as potato, mint, and alfalfa. Nematodes are unlikely to restrict growth and yield of wheat in the winter wheat-summer fallow rotation that dominates dryland production systems in eastern Oregon and Washington. However, parasitic nematode species can become numerous when dryland fields are cropped annually. Yields of winter wheat in areas infested by the cereal cyst nematode (*Heterodera avenae*) are reduced as much as 50 percent when cereals are produced more frequently than every other year or are rotated with legume crops contaminated by grass weeds (Smiley et. al., 1994). Root lesion nematodes (*Pratylenchus* species) are also found in high numbers in some eastern Oregon dryland fields when cereals are produced in annual-crop systems (Smiley, 2000). Lesion nematodes have the potential to damage dryland cereals in Washington (Mojtahedi et al., 1986; Mojtahedi and Santo, 1992), Oregon (Smiley, 2000), Colorado (Armstrong et al., 1993), Utah (Sher and Allen, 1953), Ontario (Yu, 1997), Australia (Doyle et al., 1987; Taylor et al., 1999; Vanstone et al., 1998), Israel (Doyle et al., 1987), and Mexico (Doyle et al., 1987). A better understanding of cropping systems in which root lesion nematodes become numerous, and relationships between numbers and suppression of yield potential are important as growers face increasing economic and ecological pressures to produce more annual crops and reduce tillage between crops.

This paper reports the results of a survey of parasitic nematodes in 148 samples collected from 10 eastern Oregon and Washington counties during 2000. Emphasis was on fields that are cropped annually.

Methods

Samples were collected at 109 sites during spring, summer, and autumn (May through November, 2000). Population dynamics through the season were examined by collecting an additional 39 samples at sequential dates for some sites. Emphasis was on fields planted annually, many of which were managed by planting spring crops without primary tillage. Sampling sites included 49 commercial fields, 26 large research plots in commercial fields, and 34 smaller plots at the Oregon State University (OSU) Columbia Basin Agricultural Research Center (Pendleton and Moro Stations) in Oregon and the Washington State University (WSU) Dryland Research Unit at Lind, Washington. Sampling sites were located in seven Oregon counties (Gilliam, Morrow, Sherman, Umatilla, Union, Wallowa, and Wasco) and three Washington counties (Adams, Lincoln, and Walla Walla).

At each location, 10 soil and plant sub-samples were collected and composited as single soil and plant samples for that location. Soil plus roots were collected directly in the crop row to a depth of 3 inches (6 to 8 cm) using a narrow-blade shovel (4 in; 10 cm). A hole was opened and then a thin (0.5-0.7 in; 1-2 cm) vertical slice of soil was removed and placed into a bag. About five plants with intact root systems (to about 4 inch depth) were then collected at each sub-sampling site. Plants were dug with the shovel and roots were tapped against the shovel or a boot to remove excess soil. Composite samples were placed in a cooler with ice and then stored in a refrigerator for up to 14 days before nematodes were extracted.

Data collected for each sample included site location indicators (altitude, latitude, longitude, nearest town, property owner or operator), tillage (direct drill or cultivated), recent crop history, numbers and species of parasitic nematodes, numbers of saprophytic nematodes, and symptoms of fungal root and crown diseases.

Soil mixing and nematode extraction and identification were performed by Kathy Merrifield at the OSU Nematode Diagnostic Lab at Corvallis, using a standard wet-sieving density-floatation method to extract soil-dwelling nematodes and a standard 7 day root-mist procedure to extract endoparasitic nematodes from roots (Ingham, 1994). The soil extraction procedure involves suspension of soil in water and, after allowing solids to settle for a precise time, pouring the liquid through a filter. Material retained in the filter is re-suspended and centrifuged. The pellet is re-suspended in a sugar solution and centrifuged again. The liquid containing nematodes is filtered again and examined under a microscope to determine numbers and identities of the parasitic and beneficial species. The root extraction procedure involves placing roots in a chamber and misting them for 60 seconds every five minutes for seven days. Nematodes that migrate out of the roots are collected and observed under a microscope. Once generic or species identifications are complete, the numbers are normalized to equal units of root mass (fresh weight basis) or soil (air-dry basis). All numbers in this paper are reported as lesion nematodes per gram of root tissue (e.g., xxx/g root), or lesion nematodes per kilogram of soil (e.g., xxx/kg soil). For comparative purposes, one pound equals 0.45 kg or 454 g.

Results

Nematode Species and Numbers

Samples were assessed for all species of parasitic nematodes that could be extracted and identified by the procedures used. Root lesion nematodes were identified in 94 percent (139 of 148) of samples collected. Numbers ranged from zero to 2,449/g root, and from zero to 35,960/kg soil. The dominant species of lesion nematodes were *Pratylenchus neglectus* inside roots and *P. thornei* in soil. Other parasitic genera were identified in fewer samples. Pin nematodes (*Paratylenchus* species) were present in 15 samples (10 percent of the total) and had populations as high as 7,670/kg soil under dryland conditions and 20,210/kg soil under irrigation. Stunt nematodes (*Tylenchorhynchus* species) were present in 57 samples (39 percent) and had populations up to 2,430/kg soil under dryland conditions. Cereal cyst nematode (*Heterodera avenae*) was identified in two of three Union County samples subjected to a special extraction treatment based on existing knowledge that cyst nematodes might be present in that region (Smiley et al., 1994).

Nonparasitic nematodes were present in all soils and numbers ranged from 330 to 21,890/kg soil. Numbers of beneficial nematodes had no relationship to tillage or cropping history, or to presence or absence of irrigation.

Crop Rotation and Tillage

Lesion nematode numbers were influenced by crop rotation but not by tillage (Table 1). Crops in about 40 percent of the fields had more than 300 lesion nematodes/g root, and this did not differ among no-till and cultivated fields. Winter wheat rotated with summer fallow always had less than 100 lesion nematodes/g root. High numbers (more than 300/g root) occurred in 44 percent of the situations in which crops were produced more than two of every four years. In annual crop systems, lesion nematode numbers in cereal roots and root-zone soils were slightly higher when the cereal followed a broadleaf crop rather than another cereal.

Numbers of lesion nematodes were generally lower in roots of spring barley than spring or winter wheat (Table 2). Exceptions did occur. Annual spring barley roots at one location had lesion nematode numbers comparable to those for annual spring wheat (Table 3). However, of the 13 barley samples, three (23 percent) had lesion nematodes in excess of 300/g root and ten (77 percent) had numbers below that level. Wheat roots were more evenly distributed, with 46 percent of the 102 samples having lesion nematodes in excess of 300 per gram.

Seasonal Effects

Repeated samplings from May through October revealed that lesion nematode numbers in cereal roots were lowest during the spring (May) and generally built up to their highest level as plants reached maturity (Table 2). The summer of 2000 was very dry but autumn rains began on September 3 and were frequent into the winter. Volunteer cereal and grass weed seed germinated in September and seedlings became established before the sampling date in October. Numbers of lesion nematodes in volunteer cereal seedlings and grass weeds (such as downy brome, data not shown) during October were comparable to the numbers of nematodes in planted spring and winter cereal crops during May.

Although the number of lesion nematodes inside roots became higher with plant age (from May though July), the number of lesion nematodes in soil at shallow sampling depth (3 in) was highest during spring (May) and autumn (October) and lowest during the summer months (June and July) (Table 2). Moreover, at a single sampling site it was common to find roots infested only by *P. neglectus* and soil immediately outside those roots dominated by *P. thornei.*

Table 1. Relationship of root lesion nematode numbers with tillage and cropping systems in 148 samples collected from fields in 10 eastern Oregon and Washington counties during 2000.

	Tillage		Rotation			
Pratylenchus species	Planted without tillage	Culti-vated soil	Winter wheat/ summer fallow rotation	Cropped more than 2 of 4 years	Cereal following broadleaf	Cereal following cereal
nematodes/g root	*number of fields sampled for each tillage and rotation system*					
	109	*39*	*13*	*128*	*22*	*82*
	percentage of fields in each nematode population category					
0-300	60	64	100	56	45	60
301-1,000	30	22	0	32	41	29
1,001-1,500	5	8	0	6	9	7
1,501-2,000	4	3	0	4	5	2
2,001-2,500	1	3	0	2	0	2
nematodes/kg soil	*number of fields sampled for each tillage and rotation system*					
	105	37	13	125	22	78
	percentage of fields in each nematode population category					
0-250	46	54	77	44	55	76
251-500	17	19	15	18	9	13
501-1,000	15	5	7	14	18	6
1,001-5,000	16	14	0	18	18	3
>5,000	6	8	0	7	0	3

Broadleaf Crops and Irrigation

High numbers of lesion nematodes were found in many of the broadleaf crops sampled, indicating that some broadleaf crops serve as favorable hosts for multiplication of nematodes. Some of the broadleaf crops actually seemed more favorable than cereal crops for nematode multiplication (Table 3). For instance, nematode numbers in spring wheat roots were higher when the wheat was planted after mustard, canola, or lentil than after spring wheat. The number of lesion nematodes exceeded 300/g root in each of these annual no-till crops. When an annual no-till field was planted successively to spring barley (2 years), mustard, and then winter wheat, and then divided into various broadleaf crops during 2000, the reference level of 300 nematodes per gram was equaled or exceeded in roots of lentil, chickpea, and narrow-leaf lupin. Numbers of lesion nematodes in this cropping system were much lower in roots of flax and safflower than lentil, chickpea (garbanzo bean), and lupin. Observations of high lesion nematode numbers in other commercial fields were also made for several broadleaf crops and for cereals following either broadleaf crops or grass seed crops (data not presented).

During 2000, as in 1999, there was an apparent lack of lesion nematodes in many fields in Adams and Lincoln counties of Washington. However, it was clear that the nematodes were present but below the easily detectable population levels because other fields in the same area, or on the same

Table 2. Root lesion nematode numbers in three long-term annual crops[1] managed with cultivation at the Columbia Basin Agricultural Research Center, Pendleton; spring barley, spring wheat, and winter wheat were sampled on four sampling dates during 2000.

Annual crop since 1931	May 9	June 9	July 6	October 14
		nematodes/g root		
Spring barley	26	83	211	137
Spring wheat	565	1,270	1,680	548
Winter wheat	969	-	1,243	-
		nematodes/kg soil		
Spring barley	350	90	60	210
Spring wheat	13,100	1,130	1,740	13,260
Winter wheat	460	-	2,150	8,350

[1] Plant growth at sampling dates: May -- winter wheat was nearing flag leaf and spring grains were small seedlings (planted in April); June -- winter wheat was at anthesis and spring cereals were heading; July -- all crops were mature and nearing harvest; October -- winter wheat was emerging and volunteer spring cereals were well established after rains throughout September germinated seeds lying on the soil surface.

Table 3. Root lesion nematode (*P. neglectus*) numbers in annual crops[1] planted without primary tillage at a farm near Heppner, Oregon; samples were collected during 2000.

1999 crop	2000 crop	May 9	July 9
		nematodes/g root	
Lentil	Spring wheat	1,041	627
Mustard	Spring wheat	908	1,163
Canola	Spring wheat	689	631
Spring wheat	Spring wheat	473	398
Spring barley	Spring barley	424	324
Winter wheat	Flax	-	28
Winter wheat	Safflower	-	99
Winter wheat	Lentil	-	299
Winter wheat	Chickpea	-	417
Winter wheat	Narrow-leaf lupin	-	1,764

[1] Crops prior to 1999 were no-till spring barley during 1996 and 1997, and no-till spring mustard during 1998.

farm, had high numbers that apparently occurred in response to management systems on those fields. For instance, lesion nematodes were generally not detectable in nonirrigated fields near Tygh Valley and Lind, but reached high numbers in adjacent or nearby irrigated fields (Table 4). Lesion nematode numbers near Harrington were highly variable depending on sequences of annual crops growing in nonirrigated fields.

Landscape Position

Field topography influenced numbers of root lesion nematodes. This was best exemplified in a field near Pendleton (Table 4). Lesion nematodes were much more numerous in winter wheat roots in a shallow drainage (10-30 feet wide) than in areas of the field immediately outside the drainage. Samples were collected both inside and 100 feet outside the drainage because wheat in the drainage was chlorotic and growing more slowly during the spring. The overall appearance of wheat in the drainage resembled a sulfur deficiency or damage by Pythium root rot. Wheat outside the drainage was dark green, vigorous, and looked "normal." The elevation of the drainage was only a few feet lower than the rest of the field, and the very gentle slope through the depression did not affect tillage and planting operations.

Table 4. Root lesion nematode numbers for selected pairs of nearby fields, or within-field locations, in 10 eastern Oregon and Washington counties during June and July 2000.

Nearest town and water management	Tillage[1]	Crops before 1999[2]	1999 crop	2000 crop	Nematodes /g root
Washington					
Lind	C	WW	WW	WW	17
Lind--irrigated handline	C	WW-SW	WW	SW	1,381
Harrington	N	F-WW-SW	SR	SW	0
Harrington	N	WW-CP-MT	SW	SW	930
Touchet	N	18-year SW	SW	SW	899
Touchet	N	5-year SW/WW	SW	WW	297
Oregon					
Moro	N	3-year SW	SW	SW	284
Echo	N	6-year SW	SW	WW	2,449
Tygh Valley	C	WW	F	WW	12
Tygh Valley--an irrigated circle	N	?	CA	WW	819
split into two crop systems	N	?	SY	WW	1,510
Enterprise--irrigated circle	N	SB	SB	CA	120
Enterprise--irrigated circle	N	CA	SW	SW	1,075
Pendleton--beside drainage	C	WW	F	WW	38
--wet drainage	C	WW	F	WW	390
Pilot Rock	N	SW-SW-SW	WW	SW	596
Pilot Rock	C	F-WW-F	WW	SW	55

[1] Conventional cultivation with plow and/or disk (C), or no tillage prior to planting (N).

[2] CA = canola, CP = chickpea (garbanzo bean), F = summer fallow, MT = millet, SB = spring barley, SR = safflower, SW = spring wheat, SY = soybean, WW = winter wheat.

Associated Root Diseases

Wheat and barley collected during May (61 samples) and June (43 samples) were evaluated for symptoms of root diseases caused by fungal pathogens. Symptoms of *Rhizoctonia* root rot were observed on 75 and 84 percent of the samples collected in May and June, respectively. Take-all was observed on 52 and 49 percent of the samples collected in May and June. Strawbreaker foot rot was detected on plants in 18 percent of the samples collected in May. In some instances all three diseases were detected on plants in the same sample.

Discussion

Damage Threshold Remains Unknown

This survey demonstrated that high numbers of root lesion nematodes occur in roots and soils of some annually cropped fields in low-rainfall, non-irrigated regions of Oregon and Washington. However, it is not yet possible to provide a meaningful interpretation of effects on yields by high numbers of lesion nematodes in dryland crops and soils in the Pacific Northwest. High numbers do not necessarily equate to high potential for damage because damage depends on complex interactions among the species and numbers of nematodes in or on roots, the crop species and variety, crop growth stage, crop rotation and tillage management, activity of fungal pathogens, and soil temperature, moisture and texture. Estimates of the damage potential for lesion nematodes on broad-acre field crops in the Pacific Northwest have been performed only in pots under greenhouse conditions (Mojtahedi et al., 1986; Mojtahedi and Santo, 1992). Estimates of yield damage under field conditions are needed to assess the meaning of population dynamics reported in this paper and previously (Smiley, 2000).

Although the population density above which economic damage might be predicted (damage threshold) is not known in the Pacific Northwest, reference values of 300 nematodes/g root and 1,000 nematodes/kg soil are currently being used for comparison with reports from other regions or countries (Griffin, 1984; Rivoal and Cook, 1993). These levels equate to those above which economic damage has been reported in several other regions or countries (reviewed by Smiley, 2000). However, it must be re-emphasized that threshold values for economic damage are not known for dryland field crops in the Pacific Northwest. It is anticipated that threshold values for dryland crops will be lower than for irrigated crops because the potential exists for stresses to become additive when crops deplete soil water reserves before maturity.

Response to Crops and Management

Results of the current survey indicate that root lesion nematodes are present throughout the region and can multiply rapidly in response to irrigation and certain cropping systems. Shifting from a winter wheat/summer fallow rotation to annual cropping can lead to dramatic increases in numbers of parasitic root lesion nematodes. It also appears that barley might be less favorable than wheat for multiplication of lesion nematodes, and that some broadleaf crops are favored hosts. More specific information on damage potential and crop sequence or variety effects is urgently required as growers move steadily away from rotation of winter wheat with summer fallow. Some fields previously tilled conventionally and planted to winter wheat are now being planted annually with no-till spring crops. It was encouraging that tillage seemed to have no influence on numbers of root lesion nematodes in our region. On the other hand, it was discouraging to find high populations of lesion nematodes in roots of some broadleaf crops that we currently recommend to "break the disease cycle" in cereal crops. Moreover, diseases such as *Rhizoctonia* root rot and take-all were not eliminated in wheat that followed summer fallow or crops of mustard, canola, lentil, safflower, alfalfa, and pea. These observations are important because nematodes and fungal root pathogens often interact to cause damage more severe than either of the individual agents (Taheri et al., 1994). For instance, in southern Ontario *P. neglectus* is associated closely with *Rhizoctonia* root rot of winter wheat (Benedict and Mountain, 1956). Although the fungal pathogen was considered most important, it was thought that *P. neglectus* helped initiate the root rot disease Interactions of fungal pathogens and nematode parasites have not been studied in nonirrigated crops in eastern Oregon or Washington.

Greenbridge Effect

Sequential sampling of several fields at Pendleton showed that volunteer wheat and grass weeds were heavily infested by lesion nematodes. Many growers allow volunteer to survive through the winter. If a spring crop is to be planted the volunteer and weeds are killed several weeks before the new crop is planted. If a winter wheat crop is to be planted, the field is usually cultivated, fertilized, and maintained weed free by multiple rod weedings during the summer. In each case, however, the presence of volunteer surviving through the winter greatly reduces the effective interval of the sanitizing break from one harvest to the next planting. In the case of spring cereals, the productivity of spring crops can be increased as much as 50 percent by killing volunteer and weeds during the early winter rather than waiting until early spring (Smiley et al., 1992). This phenomenon, called the "green bridge," has been emphasized for reducing damage by fungal pathogens but is to be equally applicable to nematodes, insects, and viral diseases.

Crop Genetics

Wheat varieties in Australia have large differences in genetic resistance to root lesion nematodes (Farsi et al., 1995; Vanstone et al., 1994, 1998). Different wheat varieties have up to 20-fold differences in numbers of nematodes per gram of root tissue, indicating very large differences in genetic potential to restrict lesion nematode multiplication in roots. Lesion nematodes are also known to have wide host ranges in Australia. *P. neglectus* infects all cereals as well as rotational crops such as grain legumes, pasture legumes, and oilseeds (Vanstone et al., 1994). However, nematode multiplication differs greatly in roots of various crop species and among varieties within each species (Taylor and Vanstone, 1996). Knowledge of these relationships has important implications for crop rotation strategies, as production of each crop and variety will result in varying populations of nematodes available to attack subsequent crops.

Production of a resistant crop greatly reduces lesion nematode multiplication and limits potential for yield loss in subsequent crops that may be susceptible to damage. Smiley (2000) reviewed current knowledge regarding susceptibility of various field crops to root lesion nematodes in Australia, including reasons for canola being considered a good to moderate host for *P. neglectus* and a poor host for *P. thornei*, and for canola increasing nematode numbers in soil unless the young crop is turned into soil as a green manure. Australian nematologists (Sharyn Taylor and Vivien Vanstone, personal communications) consider rye, triticale, safflower, lupin, and pea as poor hosts that may help reduce *P. neglectus* numbers in soil for the next crop. Barley and lentil are considered intermediate hosts and chickpea and wheat varieties were highly variable. It is unclear whether crop reactions will be the same in the Pacific Northwest and Australia. Crop genetics and production systems differ for these regions. We have observed that lesion nematodes reached high numbers in two lupin varieties imported from Australia, where this crop is considered a poor host for lesion nematode multiplication. Further research is needed to determine if lupin is truly a favorable host in the Pacific Northwest but not Australia and, if so, whether the difference in response is related to environment, plant variety, or nematode strain.

Species Diversity in Lesion Nematodes

The survey of lesion nematodes in the Pacific Northwest indicated that *P. neglectus* was recovered mostly from roots and *P. thornei* was recovered mostly from soil in the root zone. Since both species must rely on living root tissue to survive and multiply, it is of interest to determine if *P. neglectus* has a stronger endoparasitic growth habit than *P. thornei.* In other words, does *P. neglectus* spend a greater part of its life inside the root and *P. thornei* more time grazing superficially at the root surface? If so, and if further research demonstrates that yields are being suppressed by these parasites, the differences in their ecological habits will surely influence the efficiency of various control strategies designed to reduce their impact on yield.

Diagnostic Services

Nematode diagnostic services in Oregon are available at the OSU Nematode Diagnostic Laboratory at Corvallis (541-737-5540). Samples must be collected and handled carefully because diagnostic procedures are based on extracting living organisms that can be killed by mishandling. Descriptions of procedures for submitting samples to the lab are available at County Extension Service offices. Diagnostic services to determine numbers of each genus (*Pratylenchus*, for example) currently cost $25/sample to extract nematodes only from soil, $25/sample to extract nematodes only from plant roots, or $35/sample to extract nematodes from both soil and roots. Species identification is available for an additional $10/genus/sample.

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Addendum

Biology of Root-lesion Nematodes

Root-lesion nematodes are microscopic roundworms with complex organ systems. There are approximately 40 species described in the genus *Pratylenchus*. Root-lesion nematodes are distributed throughout the world and damage a broad range of crops, including most crop species produced in the inland Pacific Northwest: wheat, oat, barley, corn, pea, lentil, canola, mustard, potato, alfalfa, apple, and others. Wheat, canola, and chickpea are favorable hosts. Significant damage to small grain yields has been reported.

Root-lesion nematodes live freely in soil as migratory endoparasites, meaning that they may become entirely embedded in root tissue but never lose their ability to move from place to place in the root or to move back into soil. These nematodes penetrate roots by puncturing and entering the surface cells (epidermis) and then migrating throughout the root cortex. This results in surface lesions that favor greater colonization by fungal root-rotting pathogens and saprophytic bacteria, fungi, and nonparasitic nematodes. These activities reduce the ability of roots to produce branches and absorb water and nutrients.

Symptoms

Nematodes enter plants soon after seed germination, but root symptoms may not be detected until plants are older than 6 to 8 weeks. Symptoms include reduced numbers or lack of lateral branches on main roots, and dark lesions on the roots. Outer layers of root tissue (the cortex) disintegrate. Symptoms are difficult to detect in the field and are confused easily with or masked by symptoms of Pythium root rot and Rhizoctonia root rot. Affected areas of fields appear unthrifty, yellow (especially lower leaves), or droughty. Symptoms are easily confused with nitrogen deficiency, drought, or barley yellow dwarf.

Yield reductions cannot be proven without studies using nematicides, soil fumigation, or resistant and susceptible varieties. Relationships between lesion nematode populations and yield reductions are difficult to generalize over large regions because responses are influenced by climate, plant, and soil factors.

The Nematodes

Root-lesion nematodes appear worm-like under the microscope. They are about 0.5 mm (0.02 inch) long and move in water films covering soil particles. They remain active at soil moisture contents below limits for germinating seed. Three species common to nonirrigated crops in the inland Pacific Northwest include *Pratylenchus thornei, P. neglectus,* and *P. penetrans*. Species identification requires the services of a professional nematologist.

Disease Cycle

Root-lesion nematodes are motile within root tissue and soil. Females deposit about one egg per day and eggs hatch in one week. Juveniles go through about four molt stages within 35 to 40 days before becoming adults. All juvenile and adult stages are parasitic, and numbers in roots increase exponentially through the growing season. Older, dying root tissues are vacated as nematodes constantly search for young cells. These nematodes survive in an inactive, dehydrated state in roots and soil during dry or freezing conditions. They become active again when moisture, roots, and favorable temperatures return. Some species of *Pratylenchus* are more common in sands and others in clays, but the genus is not strongly restricted by soil or climate.

Control

Lesion nematode populations decline in summer fallow and are usually low in cultivated wheat/fallow rotations. Populations can become very high in direct-drill systems, especially if susceptible crops and varieties are grown repeatedly. The best control is achieved by rotations that include resistant hosts that restrict the rate of nematode reproduction. Small grain varieties vary greatly in resistance to damage.